ASTROBOTIC TECHNOLOGY: COMMERCIAL LUNAR PAYLOAD DELIVERY SERVICE. S. A. Huber[1], J. P. Thornton[2], D. B. Hendrickson[3], [1]Steven.Huber@astrobotic.com, [2]John.Thornton@astrobotic.com, [3]Dan.Hendrickson@astrobotic.com. Astrobotic Technology, Inc. 2515 Liberty Ave, Pittsburgh, PA 15222. contact@astrobotic.com.

Introduction: This paper describes Astrobotic Technology's financial and technical model for delivery of commercial lunar landing capabilities through government partnership. Topics addressed include the public-private partnership, Astrobotic's model for payload services, and *Griffin*, the lunar lander that is core to the model.

Public-Private Partnership: Astrobotic Technology is partnering with NASA to develop a commercial robotic lunar landing capability through the Lunar Cargo Transportation and Landing by Soft Touchdown (Lunar CATALYST) initiative. By partnering with Astrobotic, NASA is leveraging its half-century of exploration experience to foster a commercial ecosystem for routine lunar payload delivery. Like the successful Commercial Orbital Transportation Services program that ushered in routine, private resupply missions to the International Space Station, Lunar CATALYST brings together legacy achievements, industry resourcefulness, and disruptive innovation in a public-private partnership that is creating a remarkable new era of enterprise on the Moon.

Payload Services Model: Astrobotic Technology is a space robotics company that makes high-capability space missions possible for a broad spectrum of business, scientific, and social applications. The company is developing a robotic lunar lander to deliver and operate cargo on the surface of the Moon.

Astrobotic offers "Space Missions as a Service" by integrating multiple customer payloads into a single spacecraft with shared commodities such as power and communication. While this model exists for routine space missions (i.e., missions to low Earth orbit), Astrobotic is the first to offer it for high-capability lunar missions. Astrobotic carries customer payloads to a choice of three mission destinations. The fee is driven primarily by mass: trans-lunar injection (TLI) ($99K/kg); lunar orbit ($198K/kg); and lunar surface ($1.2M/kg for lander mount, or $2M/kg for rover mount). Customers can also purchase entire missions. Griffin's cargo mounts can accommodate a wide variety of payloads for lunar missions, including volatile prospecting, sample return, geophysical network deployment, skylight exploration, regional prospecting, lunar satellite deployment, mining, technology demonstrations, and advertising and media. Capability will be demonstrated in a first mission to deliver commercial cargo that wins the $30M Google Lunar XPRIZE, and demonstrates performance that satisfies commercial and government customer objectives for safe precision landing as well as payload delivery and support. Signed and prospective customers for this mission include NASA, international space programs, commercial ventures, and other Google Lunar XPRIZE teams.

Griffin: Griffin flies on a US commercial launch vehicle (initially the SpaceX Falcon 9) to TLI. Astrobotic's Griffin lunar lander then separates from the rocket, corrects course en-route to the Moon, enters into lunar orbit, and safely touches down on the surface.

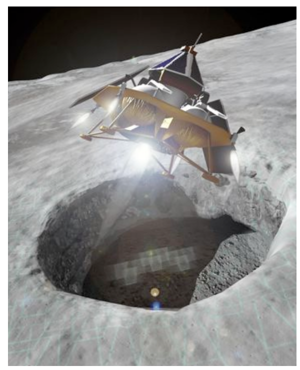

Figure 1: Griffin's first mission will fly over and land near a lunar pit

Griffin's first lunar mission will fly over and land near a lunar pit that is suspected to be an entrance to a lava tube cave. Prevalent on the Moon and Mars, pits and caves are opportunistic destinations to study origins and geology, and are potential sites for future lunar outposts. [1][2]

The mission will carry an exploration rover developed by partner Carnegie Mellon University to explore the surface and win the $30M Google Lunar XPRIZE. Carnegie Mellon brings its world-leading robotics expertise to the partnership.

Structure: Griffin's aluminum frame is stout, stiff, and simple for ease of payload integration. The main isogrid deck accommodates flexible payload mounting on a regular bolt pattern. Thermal control is available through cruise and on the surface. Four legs absorb shock and stabilize Griffin on touchdown. Rover missions can use deck-mounted ramps for rover egress. Protoflight lander structure has been qualified for launch loads through vibration testing.

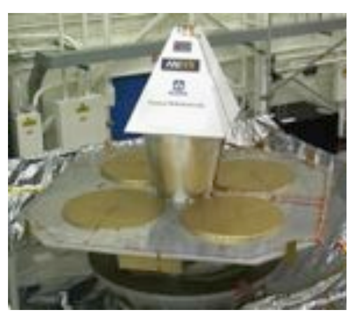

Figure 2: Griffin's primary structure vibration testing

Guidance, Navigation, and Control: During orbit and landing, cameras register Griffin to lunar terrain for precise landing, while LIDAR constructs 3-D surface models of intended landing zone to detect slopes, rocks, and other hazards. This technology enables Griffin to safely land within 100m of any targeted landing site, even in complex and hazardous terrain.

Figure 3: Griffin's precision landing and hazard avoidance system in a test flight on Masten's Xombie

Avionics: Griffin's computing platform is a combination of a radiation hardened general-purpose processor for baseline operations and a mil-spec high-speed processor. Computationally expensive operations like feature detection and hazard analysis that are required for a short period of time during landing occur on the high-speed processor. This system enables high performance and the efficiency necessary for the real-time data processing during landing.

Night Survival: Astrobotic's testing campaign has identified unique battery chemistry, power systems, avionics, and electronic components that will enable Griffin to hibernate during the lunar night, then revive the following lunar day. Nominally, primary mission operations are completed in the first lunar day and additional days support secondary and tertiary goals, until night survival is verified on the first mission.

Rover Deployment: A Griffin design option provides deployable ramps for rover egress. Once on the surface, deployable ramps enable egress of large rovers mounted to the top of the frustum ring. Ramps stow for launch and are spring-deployed upon release, accommodating both third-party rovers and Astrobotic surface rovers for payload delivery. Astrobotic rovers can support missions for any latitude – equatorial to polar. Griffin can support medium-class rovers up to 500kg.

Payload Accommodations: Griffin supports payload operation with thermal control, power, and data transmission. Deck mounting locations are thermally regulated during all mission phases. Thermal regulation is by radiation dissipation from the topside of the deck and heaters. An average of 150W of power is available to payloads during cruise and on the surface. The lander downlink can support an average of 200kbps of payload data when on the surface. A Griffin design option provides wireless surface radio to act as a communication relay for mobile rovers.

References: [1] M. Robinson, J. Ashley, A. Boyd, R. Wagner, E. Speyerer, B. R. Hawke, H. Hiesinger and C. v. d. Bogert, "Confirmation of sublunarean voids and thin layering in mare deposits," *Planetary and Space Science,* vol. 69, no. 1, 2012.

[2] G. E. Cushing, "Candidate cave entrances on Mars," *Journal of Cave and Karst Studies,* pp. 33-47, 2012.